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MODIFICATIONS OF THE *QUANTITATIVE SYSTEM OF CLASSIFICATION OF IGNEOUS ROCKS*

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During the nine years that have elapsed since the publication of the *Quantitative System of Classification of Igneous Rocks* it has been used with increasing frequency by petrographers in all parts of the world. Naturally, it has been chiefly employed in conjunction with the qualitative system as a means of more exact definition, and as an aid in the correlation and comparison of rocks from different regions. Besides the commoner rocks that belong to the systematic divisions for which magmatic names were originally suggested, numerous varieties have been described that belong to divisions not named by the authors of the system, and some that were not known to exist at the time of its publication. For these divisions magmatic names have been suggested by petrographers from time to time, and the following have come to our attention since the first appearance of the system in 1902:

I. 2.2.3. Cardiffose (F. D. Adams and A. E. Barlow, 1910).
I. 3.1.4. Taurose (H. S. Washington, 1904).
I. 5.3. Piedmontase; I. 5.3.4. Piedmontose (T. L. Watson and S. Taber, 1912).
I. 5.3.2. Mazarunose (H. S. Washington, 1903).
I. 5.5.4–5. Caledonose (Lacroix, 1911).
I. 6.2.3. Procenose (H. S. Washington, 1906).
I. 6.2.5. Raglanose (F. D. Adams and A. E. Barlow, 1908).
I. 7.1.2. Craigmontose (F. D. Adams and A. E. Barlow, 1908).
I. 7.1.3. Appianose (H. S. Washington, 1906).
I. 8.2. Monmouthase; I. 8.2.4. Monmouthose (Adams and Barlow, 1908).
I.II. 1.5. Indare; I.II. 1.5.1. Uralase; I.II. 1.5.1.3. Uralose (H. S. Washington, 1903).
I.II. 1.5.3. Dungannonase; I.II. 1.5.3.4. Dungannonose (Adams and Barlow, 1908).
I.II. 1.5.4. Borsowase; I.II. 1.5.4.3. Borsowose (H. S. Washington, 1903).

I.$_{\text{II}}$. 1.5.5. Kyschtymase (H. S. Washington, 1903).
II. 5.1.5. Kirunose (Geijer, 1910).
II. 5.3.2. Auruncose (H. S. Washington, 1906), Lincolnose (Ida Ogilvie, 1907).
II. 6.2.2. Vicose (H. S. Washington, 1906).
II. 7.1. Lujavrase (C.I.P.W., 1902). Chibinase, II. 7.1.4. Lujavrose (C.I.P.W., 1902). Chibinose (V. Hackman, 1905).
II. 7.2.2. Braccianose (H. S. Washington, 1903).
III. 4.4.4–5. Koghose (Lacroix, 1911).
III. 5.5.4–5. Ouenose (Lacroix, 1911).
III. 6.1.3. Montanose (L. V. Pirsson, 1905).
III. 6.3.2. Ottajanose (A. Lacroix, 1907).
III. 6.4.3. Papenoose (A. Lacroix, 1910).
III. 7.2.2. Jugose (H. S. Washington, 1906).
III. 7.2.3. Cascadose (L. V. Pirsson, 1905).
III. 7.3.2. Fiasconose (H. S. Washington, 1906).
III. 8.1.5. Tavose (V. Hackman, 1905).
IV. 1.$_2$. Quebeciare; IV. 1.$_2$.2. Brunase (J. A. Dresser, 1909).
IV. 1.$_2$. Hawaiiare; IV. 1.$_2$.1. Hilase; IV. 1.$_2$.1.2. Hilose (Daly, 1911).
IV. 1.$_2$.2.2. Palisadose (J. V. Lewis, 1907); Hudsonose (G. S. Rogers, 1911); Thiose (Lacroix, 1911).
IV. 2.$_1$.2. Yamaskase; IV. 2.$_1$.2.2. Yamaskose (G. A. Young, 1904).
IV. 2.$_3$.3.2. Naketose (Lacroix, 1911).
IV. 3.$_1$.2.3. Tuxenose (E. Gourdon, 1908).
IV.$_{\text{II}}$.3.$_1$.2.3. Roselandose (Watson and Taber, 1912).
V. 1.$_3$.2.2. Koswose (J. P. Iddings, 1903).
V. 1.$_4$. Gorduniare; V. 1.$_4$.1. Gordunase; V. 1.$_4$.1.1. Gordunose (U. Grubenmann, 1908).
V. 1.$_4$.1.2. Kakoulimose (A. Lacroix, 1911).
V. 1.$_5$.1.2. Guineose (A. Lacroix, 1911).
V. 2.$_5$.1.2. Permose (J. P. Iddings, 1903).
V. 3. Rhodare; V. 3.$_5$.1. Rhodase; V. 3.$_5$.1.2. Rhodose (C. H. Warren, 1908).
V.$_{\text{II}}$. 2. Mainare; V.$_{\text{II}}$.2.$_3$. Mainiase; V.$_{\text{II}}$.2.$_3$.1.2. Lermondose (E. S. Bastin, 1908).
V.$_{\text{II}}$. 5. Virginare; V.$_{\text{II}}$.5.$_5$. Virginore. (T. L. Watson and S. Taber).
V.$_{\text{II}}$. 5.$_5$.3. Nelsonase; V.$_{\text{II}}$. 5.$_5$.3.5. Nelsonose (T. L. Watson and S. Taber, 1912).
V.$_{\text{II}}$. 5.$_5$.4. Virginase; V.$_{\text{II}}$. 5.$_5$.4.5. Virginose (Watson and Taber, 1912).

There are a few synonyms in this list and in such cases we believe that the law of priority should be applied. Some names are unnecessary, such as those for presodic subrangs of percalcic rangs, viz: Caledonose and Ouenose.

Recently O. C. Farrington has applied the quantitative system to the classification of stony meteorites, and has suggested 41 new names in conformity with this system, most of them in Classes IV and V, and in subclasses characterized by prominent amounts of metallic minerals. In several cases in which meteorites belong to magmatic divisions already named for rock magmas Professor Farrington has given new names for meteoric magmas in order to distinguish the two groups of bodies.[1]

MODIFICATION OF THE FORMATION OF RANGS AND SUBRANGS IN CLASSES IV AND V

Owing to the fact that the alkali-bearing femic molecules, $NaFe(SiO_3)_2$, Na_2SiO_3, and K_2SiO_3, are not present in rocks of Classes IV and V in sufficient amounts to necessitate the recognition of the femic alkalies in establishing rangs in these classes, although it is conceivable that rocks composed almost wholly of acmite may occur, it is advisable to shift the position of femic alkalies, $Na_2O''K_2O''$, in the arrangement of the base-forming components for the formation of rangs and subrangs. Comparison between them should be made as follows:

Rangs, according to the ratio $\frac{MgO+FeO+(Na_2O''+K_2O'')}{CaO''}$

Subrangs according to $\frac{MgO}{FeO+(Na_2O''+K_2O'')}$

Sections of subrangs, when needed, according to $\frac{FeO}{Na_2O''+K_2O''}$

Subsections of subrangs, when needed, according to $\frac{Na_2O''}{K_2O''}$

For all rocks so far known, sections and subsections of subrangs in these classes are not needed and may be neglected. When noticeably alkalic prefemic rocks are found, their place in the system is provided for. By this change the symbols for magma divisions in Classes IV and V are simplified in all cases so far known, by the omission of sections of rangs. Those divisions previously called sections of rangs will become rangs with the appropriate change in the suffix. That is, the name hitherto used for the section of rang is to be retained as the name of the rang of the corresponding number, 1, 2, 3, etc., and *i* dropped from the suffix. Thus in Class IV, Order 2, Section 2 (paoliare), Rang 1 will be valbonase, and Rang 3, paolase. In Section 3, texiare, of the same order, Rang 1 will be marquettase; Rang 2 uvaldase. The name texase will be dropped unless subsequently applied to either Rang 3, 4, or 5 of this Section 3. The subrangs remain as first described and named.

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[1] Farrington, O. C., Field Museum of Natural History, Chicago, *Pub. 151*, Geol. Ser., Vol. III, No. 9, 1911.

Since in Classes II and III subgrads are formed on a basis of the chemical characters of the femic minerals, the process of determining them is to be modified in accordance with the method just described for determining rangs in Classes IV and V. That is, subgrads are to be determined by the ratio $\frac{MgO+FeO+(Na_2O''+K_2O'')}{CaO''}$; sections of subgrads, by the ratio of $\frac{MgO}{FeO+(Na_2O''+K_2O'')}$; and in the exceptional cases in which there is a notable amount of femic alkalies, subsections of subgrads are to be determined by the ratio $\frac{FeO}{Na_2O''+K_2O''}$.

Notation of divisions and symbols.—In order to avoid confusion in the symbols for various divisions in the system, it has been found advisable to number threefold divisions, when used, in conformity with fivefold ones; thus, 1–2, 3, 4–5; since the first division comprises 1 and 2 of the fivefold; the second division corresponds exactly to 3 of the fivefold divisions; and the third division comprises 4 and 5 of the fivefold divisions. This method has already been employed in a number of publications[1] since the first appearance of the system in 1902. It is also advisable to print the numbers of subclasses, suborders, and sections so as to distinguish them from the numbers of regular divisions by placing them below the line rather than above it, thus:

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[1] H. S. Washington, "The Superior Analyses," etc., U.S. Geological Survey, *Prof. Paper 28*, 1904; J. P. Iddings, *Igneous Rocks*, Vol. I, 1909, and others.

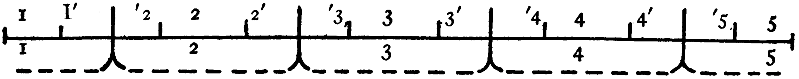
$\text{I}._{\text{II}}.\ 5.2.3.$ = Class I, Subclass II, Order 5, Rang 2, Subrang 3.
$\text{IV}._{\text{II}}.\ 2._{3}.2.2.$ = Class IV, Subclass II, Order 2, Section 3, Rang 2, Subrang 2.
$\text{IV}.\ 4._{2}.1.4.$ = Class IV, Order 4, Suborder 2, Rang 1, Subrang 4.

It is to be observed, however, that the number for subrang is placed on the line with rang. This arrangement makes it possible to express the intermediate magmatic divisions by means of marks above the line in the manner explained in the next paragraph.

Intermediate divisions.—In a continuous series of varieties of rock magmas those near one another on opposite sides of any division line are more alike than varieties at the extremities of any one division. And so it happens that some rocks differing but little in composition may be given different names, because they belong on two sides of a division line, while other rocks not so much alike are called by the same name and belong to the extremes of the same magmatic division. This condition is inherent in any rigid system of divisions of continuous series. It has not been felt to the same extent in the qualitative system because each petrographer adjusts the elastic definitions of that system to suit his own requirements, and to the confusion of everyone else.

In order to distinguish the extremes of the magmatic divisions already established in the first publication of the *Quantitative System*, and meet the needs of closer classification, or correlation, it is desirable to establish *intermediate divisions* throughout the system by placing the boundaries of these divisions half-way between the extremities of the divisions and the centers of the divisions from which the intermediate divisions are to be taken, in conformity with the methods pursued in establishing the first division in the *Quantitative System*. The boundary between adjacent divisions becomes in this way a new centerpoint for each pair of intermediate divisions.

In the notation of intermediate divisions the halves of each pair of divisions falling within the adjacent large divisions are designated as parts of the large divisions, and are not given new and independent designations. Thus the intermediate divisions in any fivefold series are as follows:



In order to simplify the expression of these divisions they are printed with prime marks as follows: 1, 1′, ′2, 2, 2′, ′3, 3, 3′, etc. A rock may belong to I, 2′, ′4, 3, or I′, 2, ′2, 3′. For convenience in determining the position of any magma with respect to these divisions a scale of ratios is given in Fig. 1. Magmas belonging to intermediate divisions may be described in terms of the variations indicated by the symbols; as, for example, I′, 3, 2′, 3 (tehamose) is a femic, calcic tehamose; more precisely, a more femic, more calcic tehamose than the central varieties, since these also contain femic and calcic components.

Transitional magma names.—It was pointed out in the first publication of the *Quantitative System,* p. 166, that a rock whose magma belongs so near a boundary line between named divisions that it should be considered a transitional variety should receive a compound magma name, made by uniting the names of the two divisions concerned and connecting them with a hyphen. The name of the division within which the magma belongs is placed last. This has been done in numerous instances, but no definite statement has been made as to the limits of the magmas that may be called transitional. It is here proposed to fix the limits half-way between the boundary between named or numbered divisions, and the boundaries of the intermediate divisions described in the preceding paragraphs. This conforms to the general principles of divisions in the *Quantitative System* and establishes a still smaller division of the petrographic series. It does not appear desirable to extend the use of compounded names to the whole range of intermediate magmas, which are sufficiently designated by symbol.

In case a rock is transitional in more than one respect, as in subrang and in rang, or in rang and order, or in class, order, and rang, or in all possible respects, it is necessary for convenience to select two magmatic names to form the compound name, and express the remaining transitions by descriptive terms or symbols. Since the magmatic name commonly employed in designating a rock is that of its subrang, the name to be compounded with it should be that of the subrang toward which it is transitional through the nearest classificatory division in which it is transitional. Thus, in the case of a rock whose symbol is II.(3)4.3(4).4; that is, one

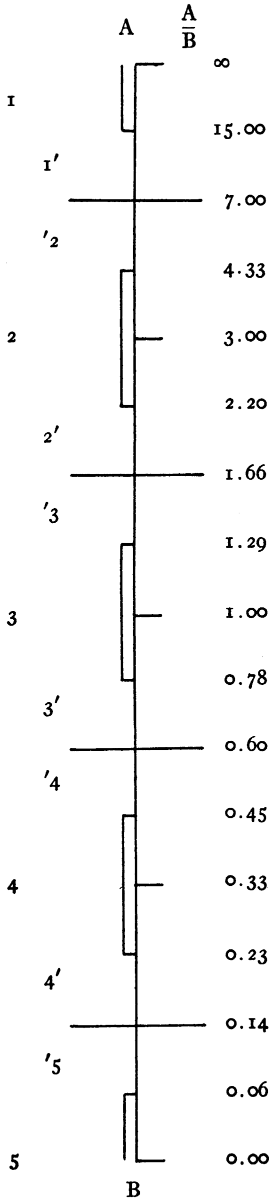


FIG. 1.—Limiting Ratios for Intermediate Magmas.

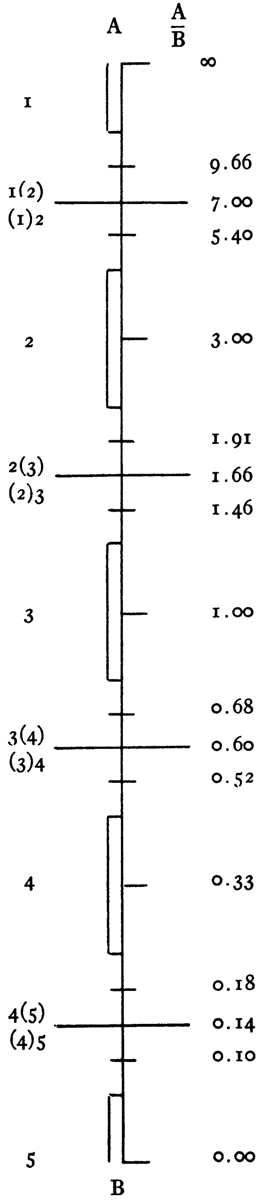


FIG. 2.—Limiting Ratios for Transitional Magmas.

which is in Order 4, near 3, and in Rang 3, near 4; the name for the subrang is tonalose, but as it is near Rang 4 it should be called bandose-tonalose; and the transition toward Order 3 should be expressed by describing it as extremely quaric bandose-tonalose. If it were transitional toward Class I, it would be extremely salic; if toward Class III, extremely femic—the term *extremely* signifying that it is *near the limit* of the division with respect to the factor named, the actual amount being small in some cases. A scale of ratios to be used in determining the limits of transitional divisions is shown in Fig. 2.

In order to express in the symbol that a rock has a *transitional* position in the quantitative classification, the number of the division toward which it is transitional is to be placed in curves, thus I.4(5).2.(3)3, or II.5.'3.4(5).

Experience has already shown that it is eminently undesirable to base subrang or other names on occurrences of *transitional* rocks.

Changes in the norm.—It has been found advisable to omit the calculation of normative sodalite and noselite on a basis of the Cl and SO_3 in rock analyses, because these substances are such small components of sodalite and noselite molecules that any error in the assignment of Cl or SO_3 to these molecules may make a large error in the amount or normative noselite and sodalite. Moreover, there are difficulties in the analytical determination of Cl and SO_3 on the one hand, and they may occur in quite different mineral compounds on the other. The method of calculating the norm has been modified, therefore, by allotting to Cl and SO_3 sufficient Na_2O to form NaCl and Na_2SO_4, and including these compounds among the salic components. This modification has been incorporated in the statement of the *Quantitative System* in Vol. I of *Igneous Rocks* by one of the authors.

The rule with regard to the allotment of CaO and TiO_2 to form titanite or perovskite is to be modified to suit those cases in which there is no excess of CaO after calculating anorthite; that is, when there is no femic CaO. In the ordinary case in which titanite, or perovskite, is formed there is femic CaO available, but there are magmas, not commonly met with, in which anorthite is associated with abundant rutile, as in certain rutile-bearing pegmatites.

From these it is seen that aluminum and calcium combine to form the orthosilicate, anorthite, in the presence of uncombined TiO_2, so that the rule regarding the calculation of titanite and perovskite, rule 3(*b*), should be modified to read: Excess of TiO_2 over available FeO is combined with CaO in the ratio of $CaO:TiO_2::1:1$ for titanite and perovskite, *after the allotment of CaO to* Al_2O_3 *for anorthite*, rule 5(*a*), and according to the silica available, etc.

Recent investigations in the Geophysical Laboratory of the Carnegie Institution in Washington have shown that the akermanite compound is $3CaO.2SiO_2$, not $4CaO.3SiO_2$ as formerly stated. This involves changes in the formulae for the calculation of normative akermanite as follows:

For the reduction of diopside to akermanite

$Y = \frac{2}{5}$ of the deficit of SiO_2
$Y =$ molecules of akermanite ($3CaO.2SiO_2$).

For the reduction of wollastonite to akermanite

$Y =$ deficit of SiO_2
$Y =$ molecules of akermanite ($3CaO.2SiO_2$)

If there is not sufficient wollastonite to satisfy the deficit of silica, recalculate the molecules of diopside and wollastonite so as to make akermanite, olivine, and diopside by means of the formulae

$$\begin{aligned} 2x+2y+\frac{z}{2} &= \text{available } SiO_2 \\ x+3y &= \text{molecules of } CaO \\ x+z &= \text{molecules of } MgO+FeO \end{aligned}$$

Where $x =$ molecules of new diopside, $y =$ molecules of akermanite, and $z =$ molecules of olivine.

Common errors in the calculation of norms.—Although clearly explained in the statements published regarding the method of calculating normative minerals in the *Quantitative System* and the method of determining rangs and subrangs, there often appears to be a misunderstanding in the minds of some petrographers as to the CaO and K_2O and Na_2O, which are to be used in determining the rang of a rock in Classes I, II, and III. It is a common error to use all the CaO and K_2O+Na_2O in the rock analysis in the ratio

$\frac{CaO'}{K_2O'+Na_2O'}$, instead of only the salic CaO and salic K_2O and Na_2O; that is, only the CaO allotted to normative anorthite, and only the K_2O and Na_2O allotted to normative orthoclase, albite, leucite, nephelite, and NaCl or Na_2SO_4. In like manner the CaO, Na_2O, and K_2O used in determining rangs, subrangs, and sections of subrangs in Classes IV and V by the ratios $\frac{MgO+FeO+Na_2O''+K_2O''}{CaO''}$, etc., are only the femic CaO and femic Na_2O and K_2O; that is, the CaO that has not been allotted to anorthite, and the Na_2O and K_2O not allotted to salic minerals.

An error is sometimes made in calculating the rangs and subrangs in classes IV and V. The MgO and FeO involved are all the MgO and FeO in all the femic minerals, silicates and non-silicates; that is, all in the rock analysis.

Misuse of the terms salic and femic.—There appears to be an indifference among petrographers as to the correct use of scientific terms, which is perhaps inherent in the conditions attending the beginnings of any new branch of science, and suggests that indifference to the manners and customs of old established communities which is characteristic of frontier life in newly settled countries. It indicates a sense of self-sufficiency on the part of the individual petrographer which, in the matter of his use of words, is typified in the conscious superiority of "Alice's" friend "Humpty Dumpty" over these servants of human speech.[1] The petrographer also has no intention of being mastered by mere words, and is in the habit of using them as he himself chooses, without regard to original definition, or others' usage. Witness the frequent misuse of the chemical terms "acid" and "basic" as applied to the limesoda-feldspar series. Oligoclase is often said to be a more "acid" feldspar than andesine, and labradorite a more "basic" one. It is not to be assumed that petrographers misusing these terms are wholly ignorant of chemistry. We, also, are petrographers and understand how we have done such things. We plead guilty to various degrees of indifference, lack of enterprise, and ignorance.

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[1] "There's glory for you," said Humpty Dumpty.

"I don't know what you mean by glory," Alice said.

Humpty Dumpty smiled contemptuously. "Of course you don't—till I tell you. I meant there's a nice knock-down argument for you!"

"But glory doesn't mean 'a nice knock-down argument,'" Alice objected.

"When *I* use a word," Humpty Dumpty said in rather a scornful tone, "it means just what I choose it to mean—neither more nor less."

"The question is," said Alice, "whether you *can* make a word mean so many different things."

"The question is," said Humpty Dumpty, "which is to be master—that's all."—*Through the Looking Glass*, by Lewis Carroll; Carl Ludwidge Dodgson, Mathematician, Oxford.

The petrographical custom of redefining any rock name to suit individual preference and the resulting multiplicity of definitions is, no doubt, in part responsible for this common indifference to all technical terms, whether distinctively petrographic or derived from other sciences. In some cases, names of rocks and technical terms have been so vaguely defined in the first instance that there is latitude of judgment in their application and an invitation to improve their definition. But when the first definition of any term has been precise and clearly specific, its misuse and distortion are inexcusable.

The terms *salic* and *femic* were applied definitely to certain minerals chosen to form norms of igneous rocks in the *Quantitative System of Classification*. They were applied strictly to calculated normative minerals: *salic* to normative quartz, feldspar, lenads, zircon, and corundum; *femic* to normative non-aluminous ferromagnesian, and calcic pyroxenes, olivines, and other minerals specifically enumerated and described. It excluded aluminous pyroxenes, amphiboles, micas, etc., to which the term *alferric* was applied.

Some petrographers have fancied the terms salic and femic as short words, which they wish to apply to modal quartz, feldspar, and feldspathoid minerals in one case, and to all modal ferromagnesian minerals in the other. These terms have also been applied to major rock groups. Such applications are not proper uses of these terms, and introduce confusion where it can be easily avoided.

Felsic and mafic.—Short expressions are useful in the general or qualitative description of rocks for the feldspathic minerals and quartz on the one hand, and for the ferromagnesian minerals on the other. The proper course is to create new terms for new or distinct conceptions, and not use one technical word in two or more quite different ways. To do so is as though some one should call all mammals *marsupials*, because he prefers the word marsupial; or should call all predaceous birds owls, because it is a short, convenient word. Since short, comprehensive terms are needed for modal feldspathic minerals, and for modal ferromagnesian minerals, and for rocks made up predominantly of these groups of minerals, we suggest the term *felsic* for the group of modal feldspars, feldspathoids, and quartz, and the term *mafic* for the group of modal ferromagnesian minerals of all kinds. The term *femag* has been used recently by Johannsen[1] for ferromagnesian minerals, but it appears to us to be objectionable both in form and in sound.

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[1] A. Johannsen. *Jour. Geol.*, XIX (1911), 319.